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INSECTS AS CARRIERS OF DISEASE

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So much has been said about insects since the War began that it is, I think, advisable that some attempt should be made to summarize our knowledge of the more important insect-borne diseases and their vectors. While insects have long been suspected of being responsible for the transmission of serious diseases, it may be said that practically the whole of our knowledge of insects in this rôle has been acquired within the past twenty years. So rapidly, however, has the charge of this offence been made out against them that, although it is common knowledge they have been proved guilty, it is not generally realized upon how many counts the verdict rests.

It has lately been my good fortune to give class instruction for the War Office to officers of the R. A. M. C. who are proceeding to the East, and, in order to bring home to my audience the importance of the connection between insects and disease, I have compiled the tables which I now publish. These can in no way claim to be complete, but merely present the more important insect-borne diseases, including important human diseases that on certain grounds are suspected of having insect vectors. With these tables I also publish one (Table VI) which includes the chief insects and acarina that are directly the cause of disease in man and his domestic animals. To complete the list of insect-transmitted diseases would demand the consideration not only of other mammals as hosts, but also of avian and reptilian hosts. In the present instance this would be to carry the subject beyond general interest, but it must be remembered, therefore, that, long as the present list of charges is, insects are not here arraigned on all the counts that might with justice be preferred against them.

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During the last few years medical entomology has been rapidly establishing itself an an invaluable branch of preventive medicine, and with the outbreak of the present War a great deal of interest and study has been devoted to this subject in Europe, notably in connection with the transmission of typhus fever by lice, and the dissemination of bacteria and other organisms by flies. Moreover, the importance of insect vectors has been generally realized, and many of the astonishing interactions between pathogenic micro-organisms and certain arthropoda have become popular knowledge.

Centuries ago insects were suggested as being possibly concerned in the spread of disease, and from time to time such logical hypotheses were advanced that it is surprising that the establishment of the truth was not sooner forthcoming. In 1577 Mercurialis, an Italian physician, suggested that plague, which was then ravaging Europe, was spread by flies feeding upon the diseased and dead, and later depositing fæcal matter on food consumed by healthy persons. This idea held ground, and various suggestions occur as to the spread of disease by flies in the literature of the eighteenth century. Edward Bancroft in 1769 advanced the theory that "yaws" was transmitted by flies feeding on diseased subjects, and carrying the contagion by settling on open wounds or scratches on healthy persons.

In 1848 Dr. Josiah Nott, of Mobile, Alabama, published a remarkable article in which he gave reasons for supposing that yellow fever was an insect-borne disease. However, although he mentioned many insects, he did not specify any insect as the particular vector.

The connection between malaria and the mosquito had long been held, it is said, by the Italian and Tyrolese peasants, and even by the natives of East Africa, but the first charge brought against the mosquito in the spread of disease by scientific authority was in connection with yellow fever.

In 1853 Dr. Daniel Beauperthuy, a French physician, wrote ably arguing that yellow fever and other fevers were transmitted by mosquitoes, but in those days there being no accepted belief in a contagium vivum, he concluded that the virus was obtained from decomposing material that the mosquito had consumed, and which

was later accidentally inoculated into man. Raimbert in 1869 showed by experiment that anthrax could be disseminated by flies.

Epoch-making in the history of our knowledge of insect vectors was Manson's discovery in 1878 that *Filaria bancrofti* was spread by mosquitoes, but at first he thought the *filariæ* escaped from the insect into water, and reached man in this manner. Later work by Manson and his colleagues determined the exact means of transmission.

It was not until twenty-eight years after Beauperthuy's theory that Charles Finlay, an American of Havana, in 1881 definitely attributed the transmission of yellow fever to a mosquito of a definite species. He had noticed the connection that seemed to exist between the presence of large numbers of *Stegomyia fasciata* and the prevalence of yellow fever. He then attempted to transmit the disease experimentally by the bites of this mosquito, and although his experiments are open to criticism, there is no doubt that he did succeed in doing so.

Three years later, in 1883, another American, A. F. A. King, advanced the first well formulated mosquito-malaria theory, and in 1898 Ross, in India, demonstrated beyond doubt the important rôle played by mosquitoes in the transmission of malaria.

In 1899 the American Yellow Fever Commission (Reed, Carroll, Lezear, and Agramonte) were sent to Cuba, and were there able to demonstrate with certainty that yellow fever is transmitted by *S. fasciata.*

It is interesting thus to note the almost parallel development in time of our knowledge of two of the most important insect-borne diseases. To deal even briefly with the historical aspects of our knowledge of other diseases tabulated below would be to consume a large amount of space, and the foregoing account will have indicated the path that has led to subsequent discoveries whose histories are readily available.

I will pass, therefore, to a few notes on each of the tables.

Notes to Table I.—Diseases of Unknown Origin

The majority of these diseases are doubtless caused by living viruses; often organisms of ultra-microscopic size, and commonly referred to as "filterable viruses."

In the case of pellagra it would appear, however, from the most recent work that, although it is still considered by many persons to be a possible insect-borne disease (and, according to Sambon, having a likely vector in either the *Ceratopogoninæ* or *Simuliidæ*), Goldberger in America considers it a disease now certainly attributable to vitamine-starvation through an unbalanced diet. If this is the case, there is no causative organism and no vector, and pellagra should be ruled out of present consideration. The question, nevertheless, is by no means settled.

The virus of acute anterior poliomyelitis is still not isolated with certainty. Flexner and his colleagues have been able to cultivate a filterable micro-organism which produced the disease in experimental animals, and more recently Rosenow and his fellow workers have isolated a polymorphous streptococcus, with which they were also able to produce paralysis in certain animals. Nuzum and Herzog were able to do likewise by a Gram-positive micrococcus isolated from the brain and spinal cord of persons dead from the disease.

Poliomyelitis has been very generally suspected of being transmitted by insects, particularly by *Stomoxys calcitrans* (the stable-fly), fleas, and *Tabanidæ* (gad-flies). Nevertheless, it appears more likely that it has an ærial transmission, infection being acquired through the buccal and nasal mucous membranes.

The causative organism of Rocky Mountain spotted fever, Wolbach claims to have discovered in the bodies of infective ticks (*Dermacentor venustus*).

Notes to Table II.—Diseases of Bacterial Origin

In the majority of cases, diseases of this class have an *indirect* transmission by insects—that is to say, instead of the organism entering the body of the host through inoculation by the bite of an insect (*direct* transmission), the organisms are carried in or on the insect's body, and are deposited by contact on human food or skin abrasions, and in this manner cause infection.

Bacillus tuberculosis may be disseminated by house-flies feeding on infective sputum, as was first shown by Spillman and Haushalter (1887), and subsequently by the investigations of other workers.

Table I.

The more important Insect-borne Disease of Unknown Origin

N. B.—Names between square brackets = certain vectors; names without square brackets = probable vectors; names followed by ? = possible vectors.

Organism	Host	Disease	Vector
?	Man ...	Dengue (breakbone fever) ...	[Sandflies (Phlebotomus), Mosquitoes. *C. fatigans; S. fasciata*]
?	" ...	Three-day fever, *syns.* "Dog disease," Sandfly fever, Phlebotomus fever	[Sandflies (Phlebotomus), Mosquitoes. *C. fatigans; S. fasciata*]
?	" ...	Yellow fever	[Mosquitoes *(Stegomyia fasciata)*]
?	" ...	Trench fever	Lice ?
? Salivary toxin? ...	" ...	Tick paralysis (American) ...	[Ticks, *(Dermacentor venustus)*]
? Salivary toxin? ...	" ...	Tick paralysis (Australian) ...	[Ticks *(Ixodes ricinus)*]
?	" ...	Rocky Mountain spotted fever	[Ticks *(Dermacentor venustus)*]
?	" ...	Japanese river fever (shima mushi)	[Mites *(Larval trombidiidæ)*] "aka mushi"
?	" ...	Acute anterior poliomyelitis ...	? Many insects have been claimed as vectors, notably *Stomoxys calcitrans?*
?	" ...	Pellagra	? Gnats of the genus Simulium have been claimed?
?	" ...	Typhus fever	[Lice]

Table II.

The more important Insect-borne Diseases of Bacterial Origin

N. B.—Names between square brackets = certain vectors; names without square brackets = probable vectors; names followed by ? = possible vectors.

The word "flies" includes in the main: *Musca domestica, Fannia* sps., *Calliphora* sps., *Lucilia* sps., and *Sarcophaga* sps.

Organism	Host	Disease	Vector
Bacillus anthracis	Man and animals	Anthrax	[Flies], *Tabanidæ? Beetles?*
" *dysenteriæ*	"	Bacillary dysentery ...	[Flies] *(Musca domestica, Calliphora* sps., *Lucilla* sps.)
" *lepræ*	"	Leprosy	Flies? Fleas? Bed-bugs? Skin mites? Mosquitoes?
" *paratyphosus A*	"	Paratyphoid fever ...	[Flies]
" " *B*	"	" " ...	[Flies]
" *pestis*	" and rats ...	Plague	[Fleas]
" *tuberculosis*	" and animals	Tuberculosis	Flies, cockroaches, fleas? Bed-bugs?
Bacillus typhosus	"	Typhoid fever ...	[Flies]
Bartonia bacilliformis x-bodies ...	"	Verruga	[*Phlebotomus verrucum*]
Spirillum choleræ	"	Cholera	[Flies], cockroaches, ants. Although the main channel of infection is the consumption of infected food and water

With the high vitality and resistance to drying possessed by the *B. tuberculosis,* the possibly long incubation period within the body and the insidious onset of the disease, the danger from *Musca domestica* in this connection is still not sufficiently recognized.

Human infection with plague and typhus has been shown to be acquired principally by the entrance of the virus through skin lesions, the insect vector having been crushed either during or after the act of blood-sucking. The stomach contents or infected excreta may be rubbed into the lesions or gain entry through abrasions caused by scratching.

This, however, does not preclude the possibility of direct infection also occurring, at least sometimes in the case of plague, as the infected flea has the proventriculus occluded by the plague organisms when the flea infection is at its height. Septicæmia following mosquito bites occasionally happens, and as likely as not the pathogenic organisms are introduced when the mosquito bites. Direct transmission by blood-sucking insects may possibly also occur in certain instances in the spread of tuberculosis and leprosy.

If Wolbach's organism (see Table I and notes thereto) is proved to be the cause of Rocky Mountain spotted fever, this will also be a disease of bacterial origin with *direct* transmission through a tick, *Dermacentor venustus.*

Notes to Table III.—Diseases of Spirochætal Origin

With these diseases the usual method of transmission is *direct* —that is to say, through the bites of the insect vectors.

Exceptions occur in the case of relapsing fever transmitted indirectly by lice, and yaws where *Musca domestica* may at times convey the organism from diseased to healthy persons.

Notes to Table IV.—Diseases of Protozoal Origin

Both *direct* and *indirect* methods of transmission by insects occur with diseases of this class. With the intestinal parasites, indirect transmission takes place by the flies feeding on fæces containing the resistant stages (cysts), and later depositing them on human food and drinking water either by regurgitation of the stomach contents, or more often *per anum,* as Wenyon and O'Con-

TABLE II.—(Continued.)

Organism	Host	Disease	Vector
Micrococcus melitensis	Man and goats ...	Undulant fever; *syns.* Malta fever, Mediterranean fever, Remittent fever	[Flies]. Although the main channel of infection is the consumption of goat's milk
Diplococcus intracellularis	Man	Cerebrospinal fever ...	Flies?
" *pemphigi contagiosi* ...	"	Tropical impetigo ...	[Lice]

TABLE III.

THE MORE IMPORTANT INSECT-BORNE DISEASE OF SPIROCHÆTAL ORIGIN

N. B.—Names between square brackets = certain vectors; names without square brackets = probable vectors; names followed by ? = possible vectors.

The word "flies" includes in the main:—*Musca domestica, Fannia* sps., *Calliphora* sps., *Lucilia* sps., and *Sarcophaga* sps.

Organism	Host	Disease	Vector
Spirochæta carteri	Man ...	Indian relapsing fever	[Lice]
" *duttoni*	" ...	African " "" (Tick fever) ...	[Ticks *(O. moubata, O. savigny)*]
" *gallinarum*	Fowls ...	Spirochætosis	[*Argas persicus*]
" *novyi*	Man ...	American relapsing fever	[Lice]
" *pertenuis*	" ...	Yaws (Framboesia)	Flies?
" *recurrentis*	" ...	European relapsing fever	[Lice]. Bed-bugs?
" *berbera*	" ...	North African relapsing fever ...	[Lice]

TABLE IV.

THE MORE IMPORTANT INSECT-BORNE DISEASES OF PROTOZOAL ORIGIN

N. B.—Names between square brackets = certain vectors; names without square brackets = probable vectors; names followed by ? = possible vectors.

The word "flies" includes in the main: *Musca domestica, Fannia* sps., *Calliphora* sps., *Lucilia* sps., and *Sarcophaga* sps.

Organism	Host	Disease	Vector
Entamœba histolytica ...	Man	Amœbic dysentery	[Flies]
*Lamblia intestinalis** ...	"	Flagellate "	[Flies]
Plasmodium malariæ ...	"	Quartan malaria	[Anopheline mosquitoes]
" *vivax* ...	"	Benign tertian malaria	[Anopheline mosquitoes]
" *falciparum* ...	"	Malignant or subtertian malaria ...	[Anopheline mosquitoes]

nor have shown recently.[1] Needless to say, infection also occurs—and perhaps principally—by mechanical and ærial transmission of the cysts to food and water.

The majority of the protozoal blood parasites have insect vectors, on which they depend solely for transmission, and in certain cases these vectors are specific: Malaria, *Anophelines;* sleeping sickness, *Glossinæ;* European relapsing fever, *Pediculi.* Other insect-borne blood parasites are apparently able to be transmitted by more than one vector, i. e., Kala-azar, bed-bug (Patton); kala-azar, *Triatoma rubofasciatus* (Donovan); Souma (*Trypanosomiasis*), *Glossinæ;* Souma (*Stomoxys calcitrans*).

Notes to Table V.—Diseases of Helminthal Origin

With the exception of possible infection with certain helminths, resulting from the carriage by flies of helminth ova from fæces and subsequent deposition of the ova on food, the insect-borne helminths all undergo part of their life-history in the body of the insect vector. Thus the adult *Filaria bancrofti* live in human lymphatic glands. The ova find their way into the blood-stream, where they hatch to the Microfilariæ, and some are taken up from the blood when a mosquito bites a person harbouring the organisms. These, if they have entered the stomach of *Culex fatigans,* or other intermediate host, soon make their way to the thoracic muscles of the mosquito, where they undergo definite metamorphosis. When this is complete (usually in from sixteen to twenty days) the worms make their way into the mosquito's proboscis, and when next it pierces the skin of some victim the filariæ burst through the proboscis sheath and make their own passage through the skin, from which they soon travel to some lymphatic gland, where they become sexually mature, and the cycle is repeated. Similarly, *Dipylidium caninum* passes part of its life-history in the rat flea, and becomes sexually mature in the dog or man. The ova are ingested by the larval flea, and infection by the cysticercoid stage follows the accidental ingestion of the flea by the definite host.

[1] "The Carriage of Cysts of *Entamœba histolytica* and other protozoa, and eggs of Parasitic Worms by House-flies, with some Notes on the Resistance of Cysts to Disinfectants and other Agents." C. M. Wenyon and F. W. O'Connor, *Journal of the Royal Army Medical Corps,* May, 1917, p. 522.

TABLE IV.—(Continued.)

Organism	Host	Disease	Vector
Leishmania tropica ...	"	Oriental sore	Flies? Fleas? Phlebotomus? Hippobosca?
" *donovani* ...	"	Kala-azar	Bed-bugs? Fleas? Triatoma?
" *sp. incerta* ...	"	Espundia	Probably some tropical blood-sucking insect
" *infantum* ...	Children	Leishmaniasis	Fleas?
Trypanosoma gambiense ...	Man	Sleeping sickness	[*Glossina palpalis* (Tsetse flies)]
" *rhodesiense* ...	"	" "	[*Glossina morsitans*] " "
" *brucei* ...	Cattle and horses ...	Fly sickness (Nagana)	[*Glossina morsitans*] " "
" *lewisi* ...	Rats	Rat trypanosomiasis	Rat louse? and [Rat fleas *(Ceratophyllus fasciatus), Ctenocephalus canis*]
" *evansi* ...	Horses, mules, camels	Surra	[Horse flies (Tabanidæ), *Tabanus striatus*]
Schizotrypanum cruzi ...	Man	Chaga's disease	[*Triatoma* (Conorhinus) *megistus*]
Babesia bigeminum ...	Cattle	Red-water fever	[Ticks *(Margaropus annulatus)*]
" *ovis*	Sheep	Piroplasmosis	[Ticks *(Rhipicephalus bursa)*]
" *canis*	Dogs	Malignant jaundice	[Ticks *(Rhipicephalus sanguineus* and *Hæmaphysalis leachi)*]
" *caballi*	Horses and mules ...	Piroplasmosis	[Ticks *(Dermacentor reticulatus)*]
Nuttallia equi	" " ...	"	[Ticks *(Rhipicephalus evertsi)*]
? Chlamydozoa ?	Man	Ophthalmia ægyptica and other ophthalmic conditions	[Flies]

*By some authorities *Lamblia intestinalis* is not regarded as pathogenic.

TABLE V.

THE MORE IMPORTANT INSECT-BORNE DISEASES OF HELMINTH ORIGIN

N. B.—Names between square brackets = certain vectors.

The word "flies" includes in the main: *Musca domestica, Fannia* sps., *Calliphora* sps., *Lucilia* sps., and *Sarcophaga* sps.

Organism	Host	Disease	Vector
Dipylidium caninum ...	Man and dogs ...	Tæniasis (tapeworm)	[Dog louse *(Trichodectes latus)*]; [Dog flea *(Ctenocephalus canis)*]; and the [Human flea *(Pulex irritans)*]
Ova of certain helminths	Man	Helminthiasis (parasitic worms)	[Flies]
Microfilaria bancrofti ...	"	Filariasis (Elephantiasis) ...	[Mosquitoes *(Culex* and *Anopheles* sps.)]
Loa loa	"	Calabar swellings	[Horse flies *(Chrysops dimidiata* and *Chrysops silacea)*]
Filaria immitis ...	Dogs	Dog filariasis	[Mosquitoes *(Culex* and *Anopheles* sp.)]
Hymenolepis diminuta	Rats, and occasionally man	Tæniasis	[Fleas]

TABLE VI.

THE MORE IMPORTANT DISEASES DIRECTLY ATTRIBUTABLE TO INSECTS AND ACARINA

N. B.—Name between square brackets = certain vector.

Organism	Host	Disease	Vector
The larvæ of *Fannia canicularis* ...	Man	Intestinal myiasis	—
" " *Piophila casei* ...	"	" "	—
" " *Eristalis tenax* ...	"	" "	—
" " *Muscina stabulans* ...	"	" "	—
" " *Sarcophaga* sps. ...	"	Intestinal, dermal and muscular myiasis	—
" " *Lucilia* sps. ...	"	" " " " "	—
" " *Calliphora* sps. ...	"	" " " " "	—
" " *Chrysomyia macellaria* (the Screw worm)	" and animals ...	Nasal, auricular, and dermal myiasis ...	—
" " *Cordylobia anthropophaga* (the Tumbu fly)	Man	Dermal myiasis	—
" " *Dermatobia hominis* ...	"	" "	[Mosquito (*Janthinosoma lutzii*)]
" " " ...	"	" "	
" " *Hypoderma bovis*, &c. ...	Cattle (occasionally man)	" " (Creeping disease in man)	—
" " *Œstrus ovis*	Sheep (rarely man)	Nasal myiasis	—
" " *Gastrophilus equi*, &c.	Horses	Gastric myiasis	—
" " *Trombidiidæ* (Harvest mites)	Man	Severe cutaneous irritation	—
Pediculoides ventricosus	"	Dermatitis	—
Tyroglyphus siro	"	" (the so-called "vanillism") ...	—
Other *Tyroglyphidæ* ...	"	" (Grocers' itch)	—
Tyroglyphus longior castellani ...	"	Copra itch	—
Sarcoptes scabiei	" and animals ...	"Itch" or "scabies"	—
Pediculus capitis	Man	Pediculosis of the head	—
" *humanus*	"	" " body	—
Phthirius pubis	"	" " axillary and pubic regions	—
Dermatophilus penetrans (Chiggers)	" and animals ...	Severe cutaneous irritation	—

THE MORE IMPORTANT INSECT-BORNE DISEASES OF FUNGUS ORIGIN

N. B.—Name between square brackets = certain vector.

Organism	Host	Disease	Vector
Achorion schonleinii ...	Man ...	Favus ...	[Lice (Pediculi)]

Notes to Table VI.—Diseases Directly Attributable to Insects and Acarina

In each case the disease results from the damage done by the insects and acarina in adopting existence upon the body of the host and living upon its tissues. The time spent upon the host may cover the whole life-history of the parasite and many subsequent generations, as with *Sarcoptes scabiei* and the *Pediculi,* or it may only embrace part of the parasite's development, as with the larvæ of flies causing myiasis. In either case the injury to the host may be so extensive as to cause death from the loss of vital tissue, or the injury itself, although insignificant, may indirectly cause death to the host by providing a suitable path for invasion by pathogenic micro-organisms.

Conclusion

It should be borne in mind that a large number of diseases included in the foregoing tables are not confined to being spread by insects, and insect transmission may in some cases only be occasional. This fact, however, cannot afford the preclusion of such diseases from consideration, and where transmission of the indirect type is possible, it is obvious that we are unable to form any just estimate of its relative importance. Probably, nevertheless, the dissemination of pathogenic micro-organisms by flies, for all that has lately been said in this connection, has not even yet been over-emphasized. It seems more than likely that *Bacillus tuberculosis* is spread in this manner from infective sputum to food (milk particularly) to a much greater extent than is commonly imagined, and there being no probability of rapid acute infection, as with *B. typhosus,* the part played by the fly is too apt to be overlooked.

Much of our knowledge with regard to insects and disease is still indefinite, as may be seen from the tables, but to anyone not particularly conversant with the subject, what we already know with certainty, even in connection with only the more important diseases that have been considered, may be sufficient to cause some little surprise.